

# **WATER EXTRACTION FROM COAL-FIRED POWER PLANT FLUE GAS**

Quarterly Progress Report

*(For the period of July 1 – September 30, 2004)*

*Prepared for:*

AAD Document Control

U.S. Department of Energy  
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Pittsburgh, PA 15236-0940

Cooperative Agreement No. DE-FC26-03NT41907  
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December 2004

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## **WATER EXTRACTION FROM COAL-FIRED POWER PLANT FLUE GAS**

### **ABSTRACT**

This quarterly report lists activities performed for the subject project. In this quarter, components for construction of the system were received, the system was constructed, and an initial test using natural gas was performed. System performance was better than expected during the first test. Water quality was good based on pH and water clarity. Produced water from the test averaged 6.0 pH compared to city tap water of 8.4 average pH. Process control strategies implemented during the test allowed the system to operate in an automatic mode by setting desired set points. The process then self-corrected to attain the set points and was very stable under this operational mode. Initial examination of the results indicate a very favorable result.

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# **WATER EXTRACTION FROM COAL-FIRED POWER PLANT FLUE GAS**

## **EXECUTIVE SUMMARY**

The goals of this project are to develop technology for recovering water from combustion flue gases to reduce the net water requirements of power plants burning fossil fuels and to perform an engineering evaluation to determine how such technology can be integrated into various power-generating systems, including steam turbine and combined-cycle plants. The work in this project will demonstrate proof of concept for a desiccant technology that is based on innovative adaptation of established principles used in absorption refrigeration. In the past, power plants burning fossil fuels were designed to generate electricity at least cost under circumstances of abundant coal and natural gas resources and adequate supplies of water for plant cooling. Future plants will need to be designed and operated to conserve both fuel and water. Water is becoming scarce and expensive in many parts of the United States including California, where there is already a strong economic incentive to reduce the net cooling water requirements of power plant subsystems cooling steam turbine condensers and scrubbing stack gases.

Future escalation in the price for natural gas and possible restrictions on carbon emissions from fossil fuels will likewise provide a strong incentive for increasing generating efficiencies. Coal utilization would be most severely impacted by climate change policy initiatives since a coal-fired steam plant emits nearly three times more CO<sub>2</sub> than a natural gas-fired combined-cycle plant with similar generating capacity. Issues of heat and mass transfer concerning water recovery, plant efficiency, and emissions are all related, so technical options for recovering water will open up new opportunities for improving performance relating to the other two factors.

The project is divided into ten tasks as follows:

- Task 1 – Desiccant Selection
- Task 2 – Desiccant Laboratory Test Evaluation
- Task 3 – Test Plan Development
- Task 4 – Test Facility and Equipment Design
- Task 5 – Equipment and Materials Procurement
- Task 6 – Test Equipment Installation
- Task 7 – Testing
- Task 8 – Test Data Evaluation
- Task 9 – Commercial Power Plant Evaluation
- Task 10 – Program Management

In the previous quarters, Tasks 1–5 were completed. In this quarter, Task 6 was completed and Task 7 initiated. All system components were received, and construction of the water extraction system was completed. The first pilot-scale test was performed during the last week of the quarter. The weeklong test evaluated several different process variables such as number of spray levels; packed-bed configuration; nozzle size, which affects spray droplet size and pattern; temperature; and processing conditions. This test consisted of firing natural gas in the furnace to

produce the flue gas for the process. System performance was excellent, and initial preliminary examination of the test data indicates favorable results. A control scheme was developed that allowed the system to operate in an automatic mode by choosing from several variables to control the process around. This indicates a stable system that will not require excessive operator attention in a full-scale scenario. Produced water quality generally had a pH in the 6.0 range in comparison to city tap water at approximately 8.4 average pH. Clarity of the produced water was also excellent. Offgas from the product was less than predicted, and filtration of the solution did not plug the filtration system, indicating low particulate formation from solution–flue gas interaction.

# **WATER EXTRACTION FROM COAL-FIRED POWER PLANT FLUE GAS**

## **INTRODUCTION AND BACKGROUND**

The goals of this project are to develop technology for recovering water from combustion flue gases to reduce the net water requirements of power plants burning fossil fuels and to perform an engineering evaluation to determine how such technology can be integrated into various power-generating systems, including steam turbine and combined-cycle plants. An ancillary objective of the engineering evaluation is to identify opportunities for integrating water recovery in ways that improve efficiency and reduce emissions of acid gases and carbon dioxide. Power plants burning fossil fuels have in the past been designed to generate electricity at least cost under circumstances of abundant coal and natural gas resources and adequate supplies of water for plant cooling. Future plants will increasingly need to be designed and operated to conserve both fuel and water. Water is becoming scarce and expensive in many parts of the United States including California, where there is already a strong economic incentive to reduce the net cooling water requirements of power plant subsystems cooling steam turbine condensers and scrubbing stack gases.

Currently, coal-fired power plants require access to water sources outside the power plant for several aspects of their operation in addition to steam cycle condensation and process cooling needs. In integrated gasification combined-cycle (IGCC) systems, significant water is used in the coal gasification process and for syngas saturation, which is lost through the power plant stack. In pulverized coal (pc) power plants, water inherent in the coal as well as water associated with flue gas scrubbing is lost through the stack. Currently, the strategy used to reduce water consumption in areas where water restrictions are stringent is to employ an air-cooled condenser as opposed to once-through cooling or a cooling tower. However, even plants with air-cooled condensers to minimize water consumption require a significant amount of water in several cases in order to allow for required steam drum blowdown, power augmentation systems, and gas turbine inlet evaporative cooling or fogging systems. At the present time, there is no practiced method of extracting the usually abundant water found in the power plant stack gas. Some work has been done on using mechanical heat rejection to condense water vapor. Such systems would require massive and expensive heat rejection equipment, would be severely limited by high ambient temperatures, and would result in decreased gas turbine performance as a result of higher back pressure due to closed heat exchangers in the flow path. The process being investigated in this project uses liquid desiccant-based dehumidification technology to efficiently extract water from the power plant flue gas, requires minimal heat rejection equipment, can function across the entire ambient range, and results in only a small increase in exhaust pressure.

The advantage of using a desiccant is to facilitate the recovery of useful amounts of water at flue gas temperatures that can be reasonably achieved during power plant operation. Direct contact cooling with a desiccant solution can be engineered to minimize pressure drop, and any water evaporating into the flue gas from an upstream scrubber would be recovered for reuse. The alternative of indirect cooling in an air/flue gas-condensing heat exchanger without a desiccant, which would be limited to applications involving low ambient temperatures, raises significant

engineering and economic problems involved with the size and cost of the heat exchanger, pressure drop, corrosion, and fouling, and discharge of nonbuoyant stack gas.

This project is a 2-year program to demonstrate the feasibility and merits of a liquid desiccant-based process that will efficiently and economically remove water vapor from the flue gas of coal-fired power plants (IGCC and pc steam plants) to be recycled for in-plant use or exported for clean water conservation. Reduction of water consumption by power plants is quickly becoming a significant issue when attempting to obtain permits for power plants and when required to meet new, more restrictive water consumption allowances currently being considered by the U.S. Environmental Protection Agency (EPA) under proposed Rule 316b.

## **EXPERIMENTAL**

The initial task in the project, Task 1, was an investigation of the potential viability of various desiccants to meet performance requirements in this application. The selection of a desiccant for the proposed system hinged on several criteria. These criteria were identified, applicable chemical/physical/environmental/cost data were gathered, and the data compared. A weighted ranking system based on a criteria list was developed for use in the evaluation and comparison of the candidate desiccants. Three candidate desiccants were chosen for further testing in a bench-scale system.

In the second quarter, Task 2 was completed. The objective of this task was to test the candidate desiccants selected in Task 1 using the Energy & Environmental Research Center's (EERC's) conversion and environmental process simulator (CEPS). Based in part on the results of this testing, a final desiccant was selected. This selected desiccant was chosen to be used in the larger pilot-scale Water Extraction from Turbine Exhaust (WETEX) demonstration using the EERC's slagging furnace system (SFS) as a flue gas source.

In the third project quarter, Tasks 3–5 were completed. This involved system design for the larger pilot-scale testing and developing a preliminary test matrix device which was reported to the U.S. Department of Energy (DOE). System components and necessary hardware were ordered, and scheduling for construction and testing was completed.

In this quarter all system components were received, construction of the system was completed, and the initial test run was completed the last week of the quarter. Figure 1 shows a schematic of the general process layout. Figure 2 shows the absorber column being constructed on top of the weak desiccant tank, a plastic, welded 500-gallon tank designed to hold enough solution to manage any surges that may occur. In Figure 2 on the right side is the inlet piping for the flue gas to enter the tower. Figure 3 shows the absorber tower prior to insulation and Figure 4 shows the tower after insulation with the six levels of spray nozzles indicated by the clear tubing. It can be seen in the figure that the bottom three spray levels are at intervals not equal to the upper three spray levels, and this is due to the fact that the lower portion of the tower was new construction and the upper section was from a previous project which had ports already in place. Figure 5 shows the flash tank with heat tape prior to insulation, and Figure 6 shows the desiccant

# Process Layout Diagram

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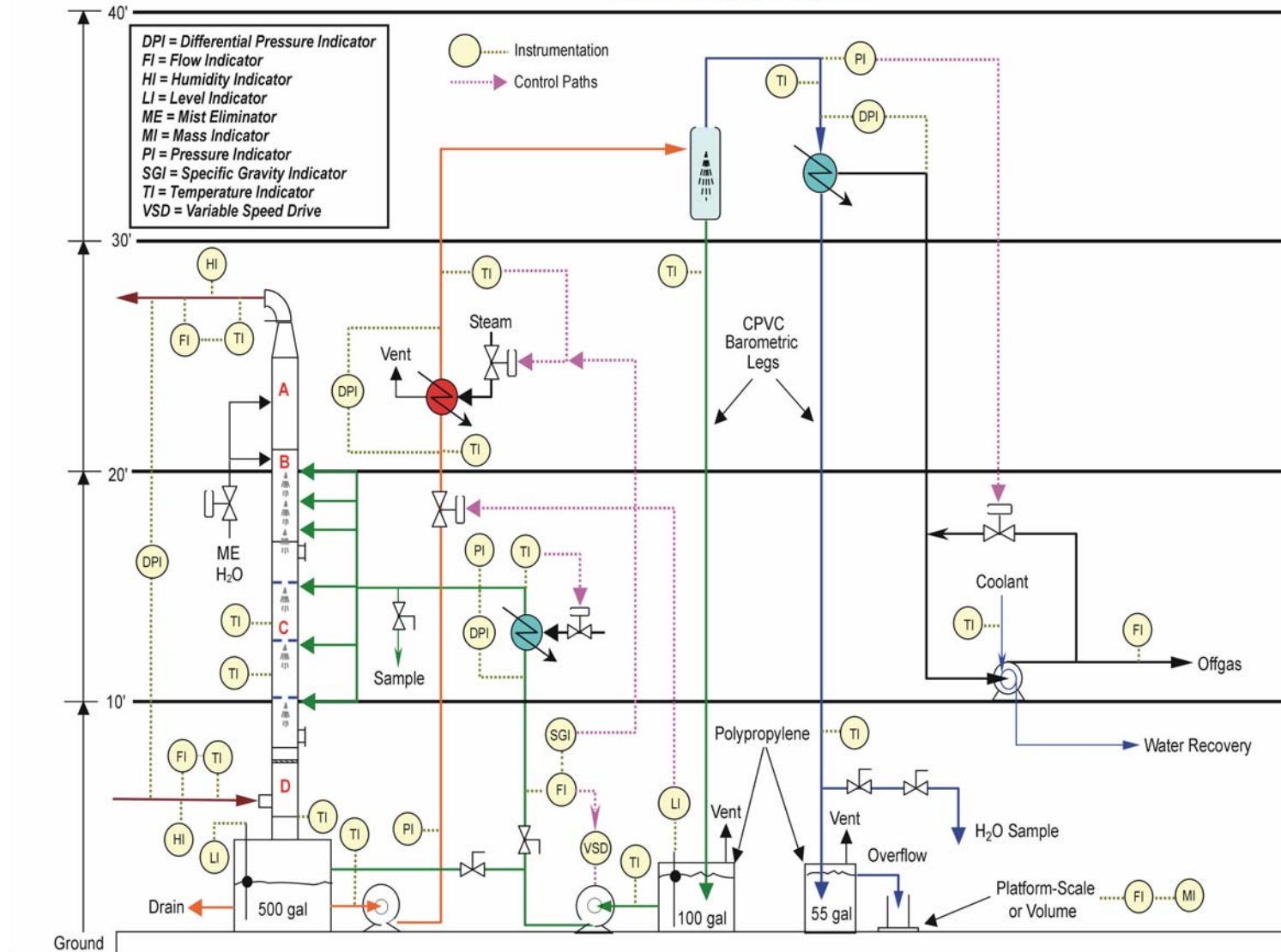


Figure 1. Schematic of the general process layout.



Figure 2. Construction of the absorber tower.



Figure 3. Absorber tower prior to insulation.



Figure 4. Absorber column after insulation.



Figure 5. Flash tank prior to insulation.



Figure 6. Solution inline heater.

heater in-line prior to the flash tank. The grey piping in Figure 5 is the inlet solution line after having passed through the solution heater shown in Figure 6. This heater uses in-house steam with an air actuated control valve to regulate the temperature of the desiccant solution entering the flash tank. Figure 7 shows the top of the flash tank and the cooler to condense water vapor. This cooler is regulated using city water as the heat transfer fluid at nominally 40°F. Figure 8 shows the two system tanks at the bottom of the absorber tower and the barometric leg, with a 500- and a 100-gallon capacity, respectively. In the right side of the image is a u-shaped Coriolis meter to measure solution concentration on line. The lower left of the image shows the top of the in-line filters, which are also shown in Figure 9. When introducing solution into the system, the solution is passed through these filters to remove any particulate and foreign material. During operation, the solution is continuously passed through the filters to remove particulate that may have accumulated in the solution. Figure 10 shows the produced water recovery barrels and scale. The double-valved pipe stub at the upper left in the image is used for collecting samples of produced water for analysis of quality. Figure 11 shows a typical in-line temperature and pressure port, which is continuously logged by the computer control and data acquisition system. Figure 12 shows the experimental setup for evaluating flow and spray characteristics of different nozzle sizes and also the flow distribution of the solution through packing as shown in Figures 13 and 14. Figure 15 shows the type of spray nozzles used in this pilot test system. Several sizes were used throughout the test in both the flash tank and the absorber tower. Different flow rates, pressures, and number of spray levels were tested.

## RESULTS AND DISCUSSION

The test matrix and sampling plan are detailed elsewhere. Several process conditions were tested during the last week of this quarter in the first pilot-scale test. Different flow rates, spray



Figure 7. Top of flash tank and condenser.



Figure 8. Solution tanks and Coriolis meter.



Figure 9. Solution filtration system.



Figure 10. Cascading water recovery barrels and scale.



Figure 11. Typical temperature and pressure port.



Figure 12. Spray nozzle and packing flow evaluator system.



Figure 13. Spray nozzle flow evaluation.



Figure 14. Packing flow evaluation.



Figure 15. Example of spray nozzle used in system.

levels, nozzle sizes, solution temperatures, as well as a packing versus spray tower configuration are examples of the types of variations that were attempted during this first pilot-scale run. For this first test, the SFS was fired using natural gas. A control system was implemented that allowed the process to be controlled to a set point of several different conditions. For example, the system could be placed under automatic control to keep the system solution concentration at a set value. In this mode, all of the heat exchangers would self-correct to keep the solution at the desired concentration. Other set points, such as temperature, could be chosen as the control point as well. One of the initial concerns entering into this project was how operator-intensive this process would be. Having to have an operator constantly monitoring the system would have been a barrier to industry acceptance. The system performed very well under automatic control, indicating that the process would require little operator attention in a full-scale scenario. Figures 16 and 17 are screen captures of the control computer. Figure 16 shows the process schematic and typically would list flow rates, temperatures, pressures, etc. Most of the process variables have been removed from this screen for proprietary reasons. Figure 17 is an example of real-time tracking of process variable trends. The lines represent different process variables that are being tracked such as temperature of solution into the tower, temperature of solution into the flash tank, absorber tank solution level, and solution concentration at different points in the system. This figure is shown to illustrate the stability of the system under automatic control. All process variables being tracked in this graph are flatline, indicating a very stable process. Initial process designs and estimates of process conditions were generated using process chemistry models. From a limited evaluation of the data during the test run, several items of interest were noted. Offgas of undesirable species such as  $\text{SO}_2$  and  $\text{NO}_x$  from the solution was less than predicted. Produced water quality was good, based on pH and clarity. The pH of the produced water was for the most part about 6, with an excursion in one test to 4.2, which has not yet been explained.

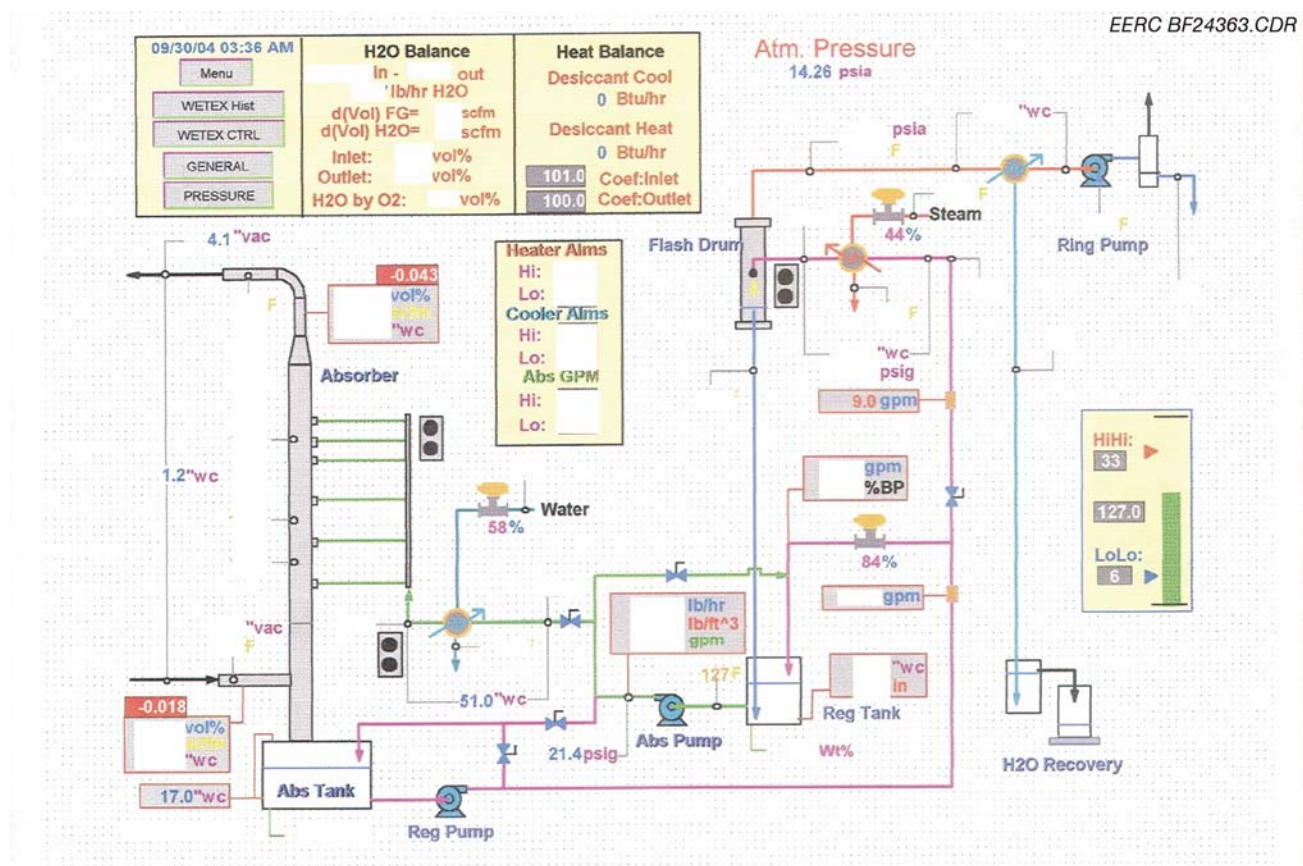


Figure 16. Screen capture of control computer.

City water pH tested at approximately 8.4. Lab testing of the water will need to be performed before total quantitative results can be given. Bypassing a large portion of the weak solution around the flash tank worked well. Initially this was thought to be less than promising, however, initial results indicate that when large liquid-to-gas ratios are used in the tower, a small portion of the entire solution stream can be run through the flash tank while bypassing the majority around the tank, and system parameters can still be held steady. This would allow for reduced parasitic power draw in a full-scale plant, reducing operational costs as well as reduced capital cost for smaller equipment for that portion of the process if this were the desired process design. The spray tower configuration compared well to the packed-bed configuration. Pressure drop across the packed bed will be of concern for this configuration if fired on coal. Carryover of the solution into the gas stream was measured by EPA Method 5 sampling. This was also used to verify the online continuous moisture measurement (CMM) instruments. Particulate matter from the Method 5 testing was virtually nonexistent, indicating no carryover of solution into the gas stream. Solution quality based on pH also appeared to be good. As with the produced water, lab tests will be needed to ascertain any contamination issues, however, the online gas monitors before and after the tower contact zone indicated very little pickup of gas species in the solution.

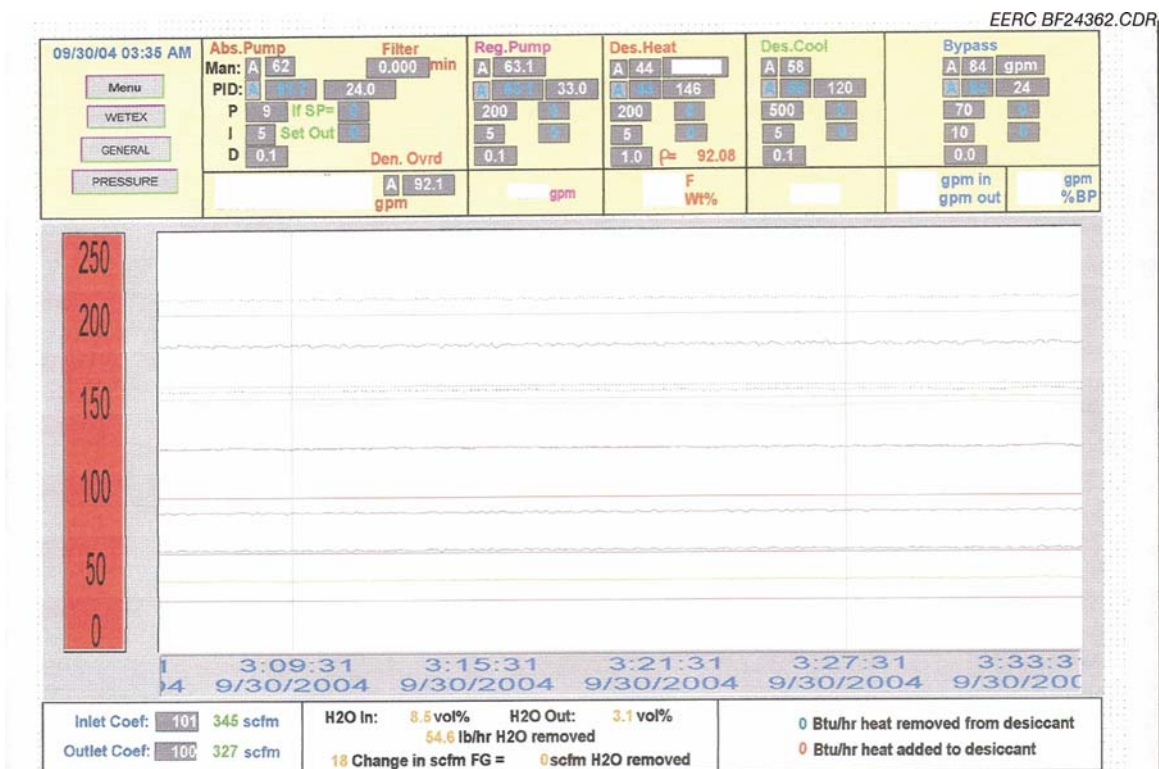


Figure 17. Screen capture of process variable tracking.

## CONCLUSIONS

Work on this project is proceeding as scheduled in this quarter. The system was constructed and, in the last week of the quarter, the first pilot test performed. Initial examination of the data indicate that the performance of the system was better than predicted by chemical process models. The weeklong test evaluated several different process variables such as number of spray levels; packed-bed configuration; nozzle size, which affects spray droplet size and pattern; temperature; and processing conditions. Produced water quality is good based on pH and clarity but will require laboratory analysis for quantitative results. Offgas from the solution was less than predicted. The system's overall performance was excellent, and it operated very well in auto control modes, indicating the process will not require excessive operator attention under commercial operation. Since the test was performed at the end of the quarter, more in depth analysis of the collected data will be performed in the next quarter and reported with the results from the second pilot test firing coal.